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RESEARCH SUMMARY

INTEGRATION OF OFF-RAMP AND ARTERIAL SIGNAL CONTROLS TO MINIMIZE THE RECURRENT CONGESTION ON THE I-495 CAPITAL BELTWAY

Problem

Effectively contending with the growing congestion on the Capital Beltway has long been a challenge for transportation professionals in the region. Although a variety of factors have contributed to its deteriorating traffic conditions, insufficient freeway capacity to accommodate the ever-increasing demand from the Washington Metropolitan Area, is an issue that needs to be addressed. Extensive field observations of the congestion patterns on the Capital Beltway in recent years has revealed that many existing bottlenecks during peak hours are due to the spillback of the traffic queue from an off-ramp that often takes away the capacity of one to two mainline travel lanes when it exceeds the length of an auxiliary lane. Examples of bottlenecks caused by such off-ramp spillback vehicles can be found at the Connecticut Avenue and Georgia Avenue interchanges during peak hours.

Objective

While policy makers explore demand-side methods, such as congestion pricing and High Occupancy Toll lanes to deal with congestion on the Capital Beltway, the objective of this project was to investigate the potentially cost-effective and near-term deployable strategy of integrated off-ramp control.

Description

To meet the objective, the study focused on developing an integrated off-ramp and arterial signal control system for urban interchanges that can dynamically adjust the signal plan to minimize the queue spillback from off-ramps to the freeway mainline while maximizing throughput on their neighboring arterials. The entire system consists of the following three primary components: (1) a real-time operational framework to effectively contend with the impact of off-ramp queue spillback on both the freeway and arterials within the interchange control boundaries; (2) an arterial control model to optimize signalizing timings at all oversaturated intersections within the impact boundaries of a congested interchange; and (3) an integrated interchange control model to minimize the total freeway and arterial delay if any off-ramp queue has spilled back to the freeway mainline.

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Unlike most existing models on interchange traffic control, the focus of this research was on the scenario in which traffic volumes on both the freeway and its local arterial are high enough to cause intersection overflow and off-ramp spillback to the freeway mainline segment. Hence, the development of control algorithms to optimize the overall operational efficiency for such congested interchanges needs to consider the tradeoff between freeway and arterial traffic delays, while also accounting for potential lane blockages at local intersections due to oversaturated traffic conditions during different control periods.

Both field observations and simulation experiments conducted in this study further indicate: that (1) an interchange's high off-ramp volume, in conjunction with the peak-hour arterial flow rates, will cause some intersection approaches to become oversaturated, consequently paralyzing traffic movements along the entire arterial; (2) an oversaturated arterial adjacent to the interchange can cause off-ramp queue lengths to extend beyond their auxiliary lanes and block the freeway's mainline lanes; and (3) state-of-the-art signal optimization programs, such as TRANSYT-7F, cannot yield effective signal control plans for oversaturated arterials that often experience lane blockage between neighboring lanes and queue spillback to their upstream segments.

Results

An extensive evaluation conducted in this study using both the field data and various experimental scenarios convincingly indicates that the proposed system framework with its embedded control models is capable of capturing interactions between turning and through traffic flows, as well as congestion propagation between neighboring intersections. It can also effectively prevent the formation of local bottlenecks caused by queue spillback or lane blockage. Further analysis of the traffic queue patterns also shows that, by accounting for how off-ramp queues impact delays of both freeway and arterial traffic, the interchange optimal control system can yield the best use of a roadway's overall capacity and prevent the formation of freeway queues in the interchange area caused by the overflow of off-ramp traffic. Hence, the integrated control model developed from this study can potentially serve as an effective tool for highway agencies to exercise the proper level of control, based on the detected distribution of ramp queue length, and traffic volumes on the freeway as well as arterials.

Report Information

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